

E951

Cryogenics for

Pulsed Solenoid Magnet

Design, Operation, Safety
Project Plans

BNL
Cryogenic Safety Committee
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Components

- 1). Pulsed Solenoid Magnet
- 2). LN₂ Storage Dewar: 5.88 kgal.
- 3). Vacuum Pumps, Ambient HEs
- 4). GHe Circulator/HE
- 5). LH₂ Storage Dewar: 14 kgal.
- 6). Interconnections
 - a). VJ lines, valves
 - b). LN₂ Trailer Fill station
 - c). LH₂ Trailer Fill station
 - i). LH₂ P&P plumbing
 - ii). GN₂ Purged vent stack
- 7). Cryogenic Controls
 - a). Physical
 - b). Automatic
 - i). Alarms, pager
 - ii). Interlocks
- 8) Gas Sensors
 - a). Oxygen
 - b). Hydrogen

Operating Modes: Magnetic Field, Cooled by.

1. 5T: LN₂ direct,
2. 10T: pumped LN₂ direct,
3. 5T: GHe cooled by LN₂.
4. 10T: GHe cooled by pumped LN₂.
5. 15T: GHe cooled LH₂.

Max. Dynamic Loading: 15T operation

Dynamics

- 1). Dynamic: 15.0 MJ/pulse (+54K)
Peak = $54 \times 5.5 \text{ J/gK} \times 100 \text{ g/s} = 29.7 \text{ kW}$
- 2). 30-minute repetition-rate (spec.)
- 3). $15.0 / (30 \times 60) = 8.33 \text{ kW}$ average
- 4). Background ca. = 1.66 kW
- 5). LH₂ avg. dynamic consumption rate;
 $(10 \text{ kW} / (445.4 \text{ J/g})) \times (3600 \text{ (s/h)} / 71 \text{ g/l})$
= 1138.4 lph = 300 gph
- 5). LH₂ Dewar use: 14 kgal., dynamic
Hrs/Dewar = $14,000 / 300 \text{ gph} = 46.7 \text{ h}$
 $46.7 / 8 = 5.8$ (8-hr op. shifts/Dewar)
- 6). LH₂ Dewar use: 14 kgal., standby
Hrs/Dewar = $14,000 / 50 \text{ gph} = 280 \text{ h}$
 $280 / 8 = 35$ (8-hr standby shifts/Dewar)

Discussion:

- 1) Equipment Block Diagram

- 2) Equipment Layout
- 3) General Arrangement (Schematic)
- 4) Circulator/HE Excerpt
- 5) Pulsed Solenoid Magnet Excerpt
- 6) GOP Text
- 7) GOP flow diagram examples (two)
- 8) Safety considerations
 - a) Equipment
 - i) 14 k gallon LH₂ Dewar (143 psig)
 - ii) 5.88 gallon LN₂ Dewar (65 psig)
 - iii) PSM Cryostat (MIT, later)
 - iv) Circulator Bath (DA=300 psig, new set pressure = 4 atmos.)
 - v) GHe Circuit (B31.3 DA=200 psig)
 - vi) Interconnecting piping (150/200)
 - b) Equipment Design, Siting
 - i) BNL OHSG, Special Precautions for Locations Containing Flammable Atmospheres 4.12.0
 - ii) BNL ESH, 5.1.0 Non Flammable Cryogenic Liquids, Rev.2
 - iii) BNL OHSG, Flammable Cryogenic Liquids 5.2.0
 - iv) NFPA 50B, Standard for Liquefied Hydrogen Systems at Consumer Sites, 1999 NFPA

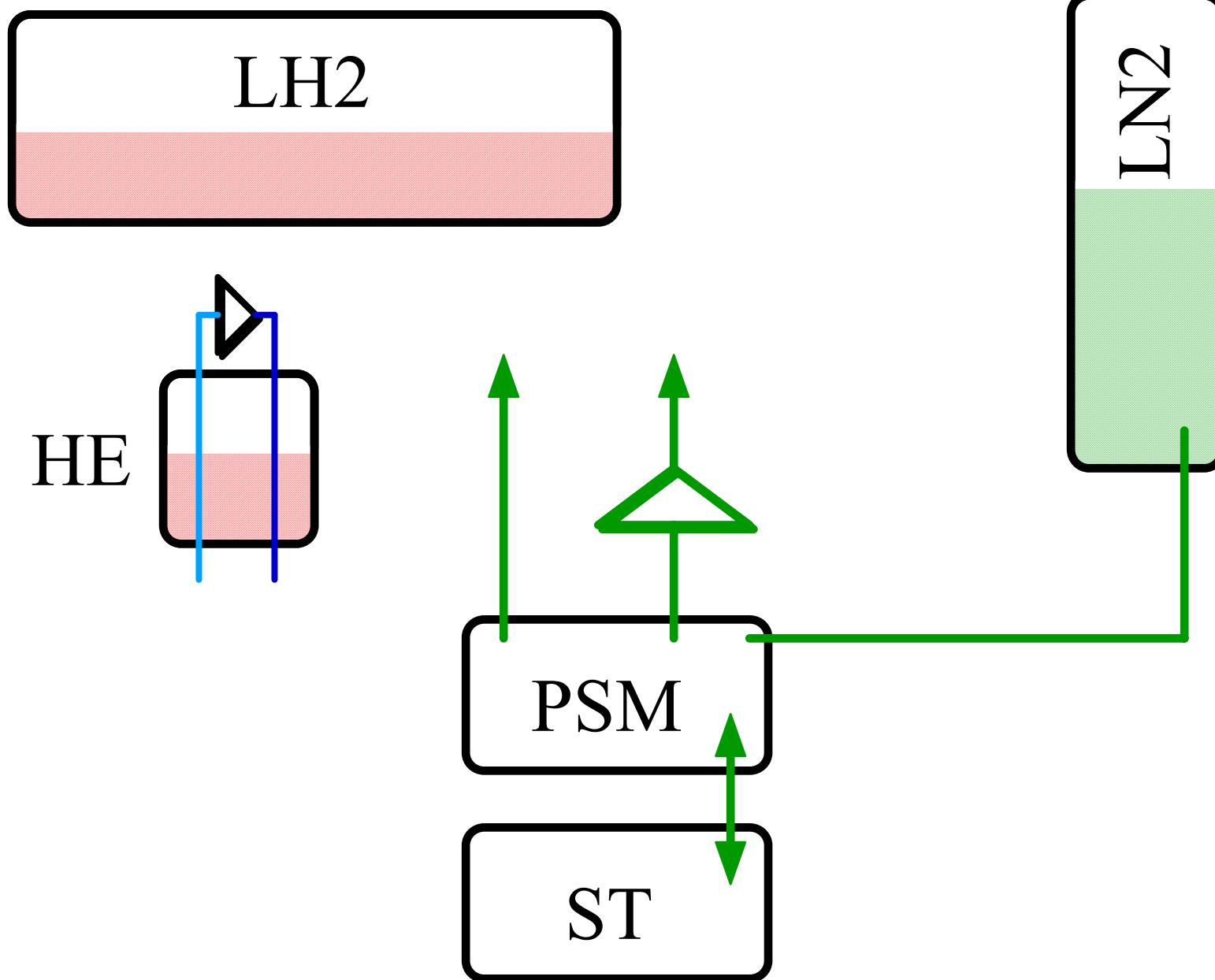
- v) CGA G-5.4-2001, Standard for Hydrogen Piping Systems at Consumer Locations, 2nd Edition
 - vi) CGA G-5.5-1996, Hydrogen Vent Systems, 1st Edition.
- c) Final System Documentation
- i) Configuration Documented
 - ii) Safety Issues Documented
 - iii) Pressure Tests Documented
 - iv) Operating Procedures Complete
 - v) Final System Details Documented
 - vi) Final CSC review

Pulsed Parameters

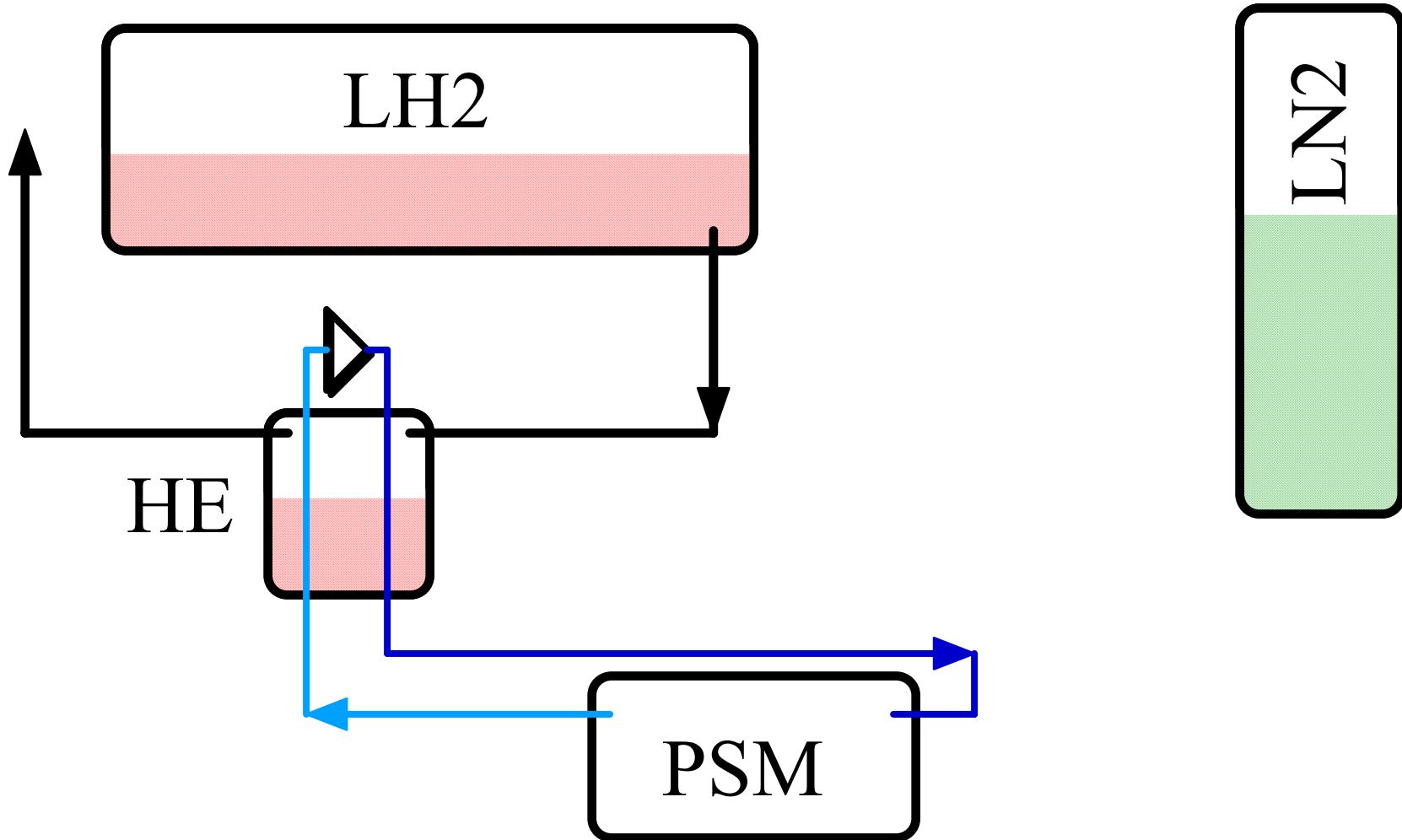
75 T/layer	Field	T ₀	Energy	T _{max}	ΔT	Cycle
Units >	T	K	MJ	K	K	minutes
LN ₂	5.0	84	2.4	90	6	6
LN ₂ Pumped	10.0	74	7.9	95	21	20
LH ₂	14.5	30	13.5	78	48	20

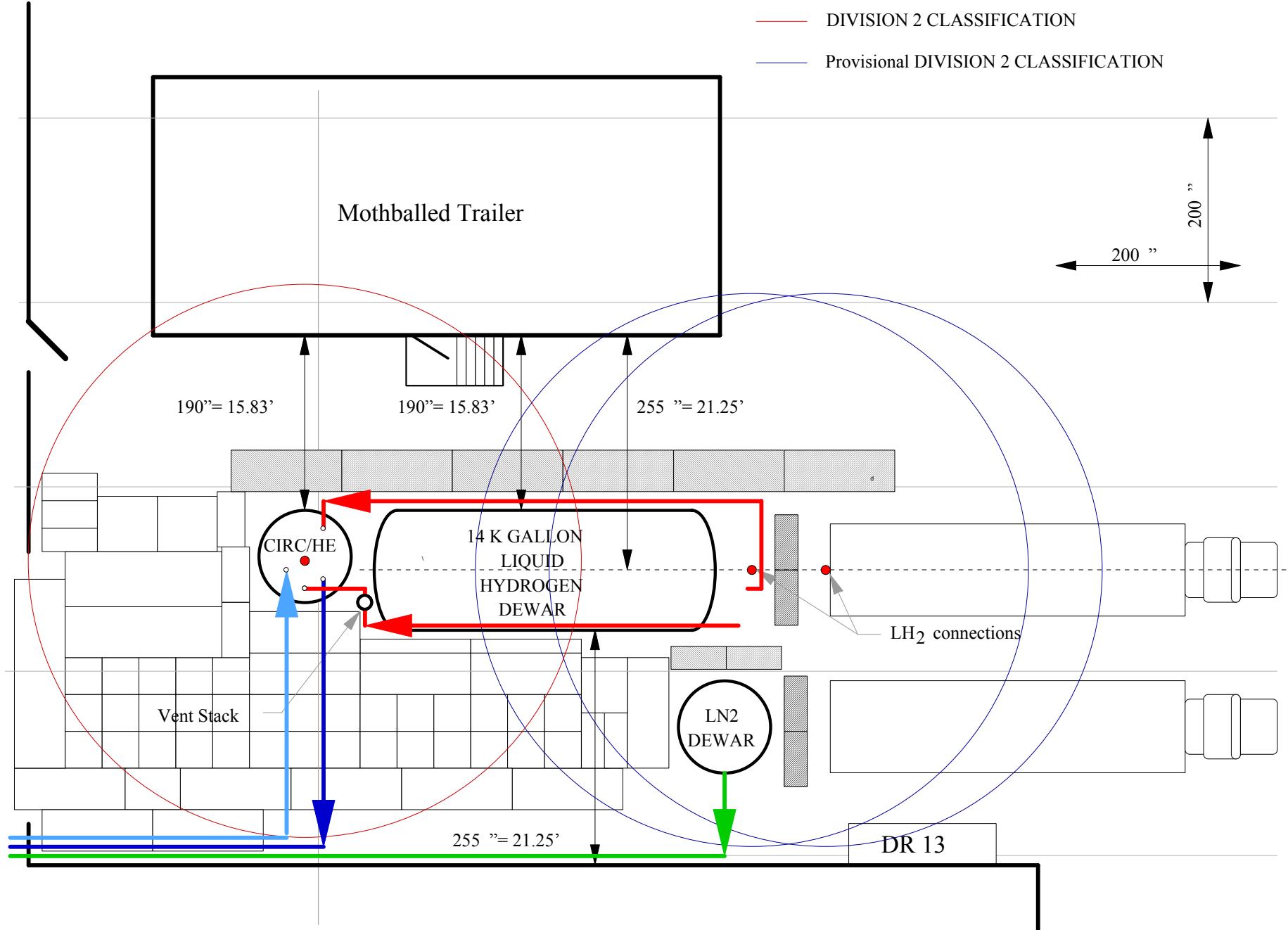
78 T/layer	Field	T ₀	Energy	T _{max}	ΔT	Cycle
Units >	T	K	MJ	K	K	minutes
LN ₂	5.2	81	2.6	87	6	10
LN ₂ Pumped	10.4	70	7.9	91	21	30
LH ₂	15.0	26	15.0	80	54	30

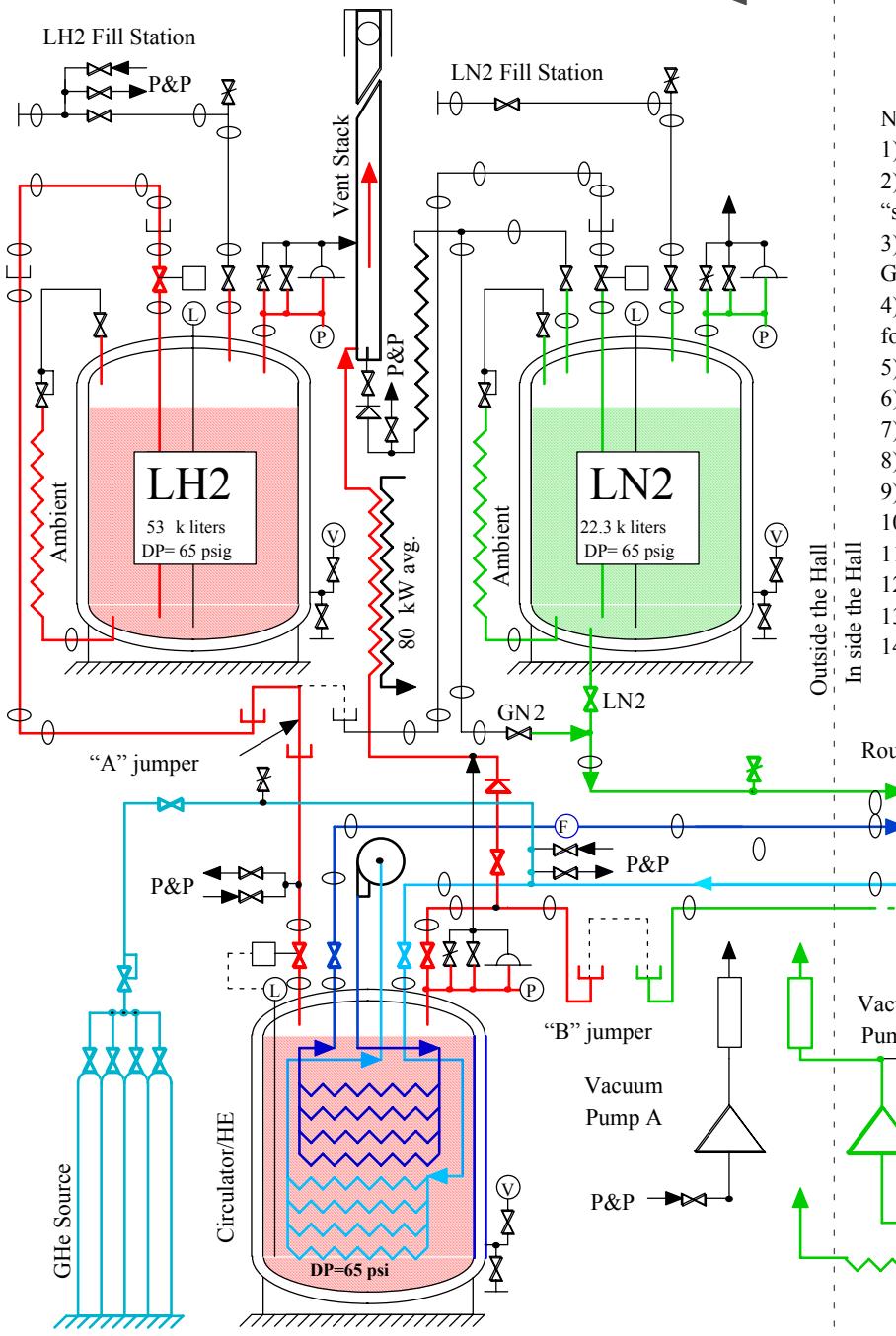
LN2 Scenario



LH2 Scenario



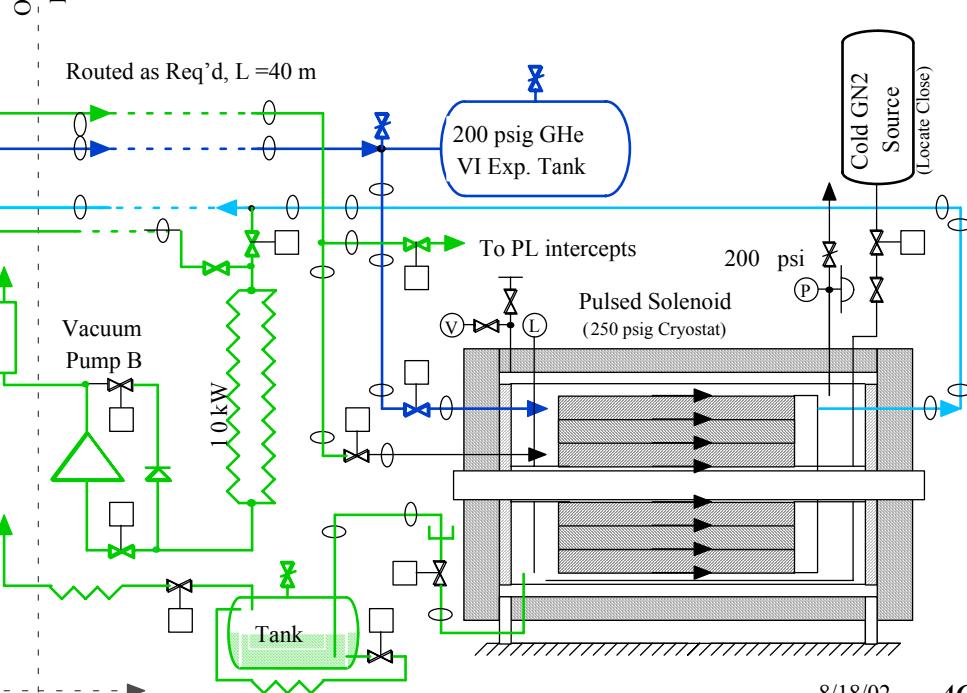




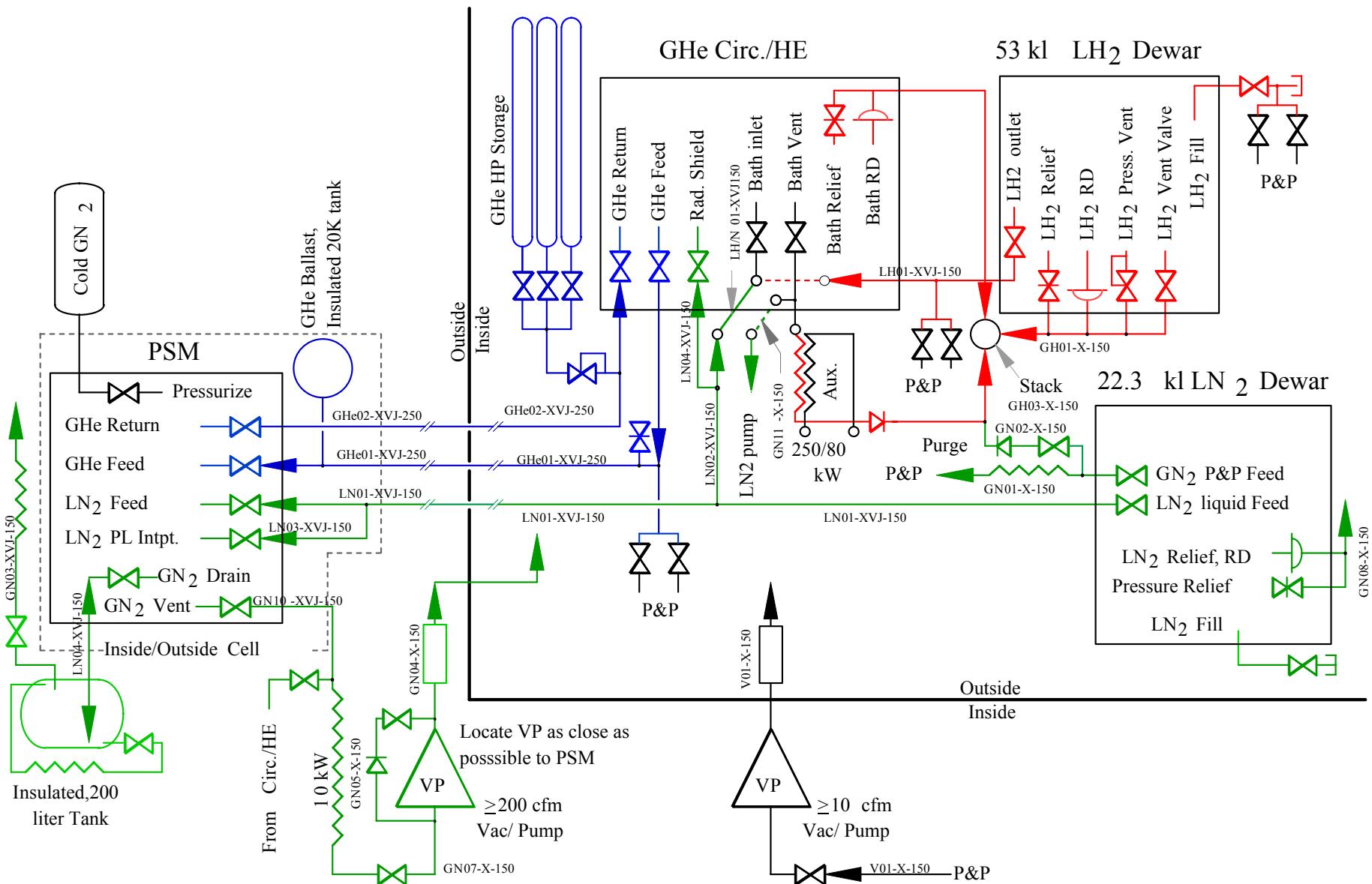
E951 Pulsed Solenoid Cryogenics

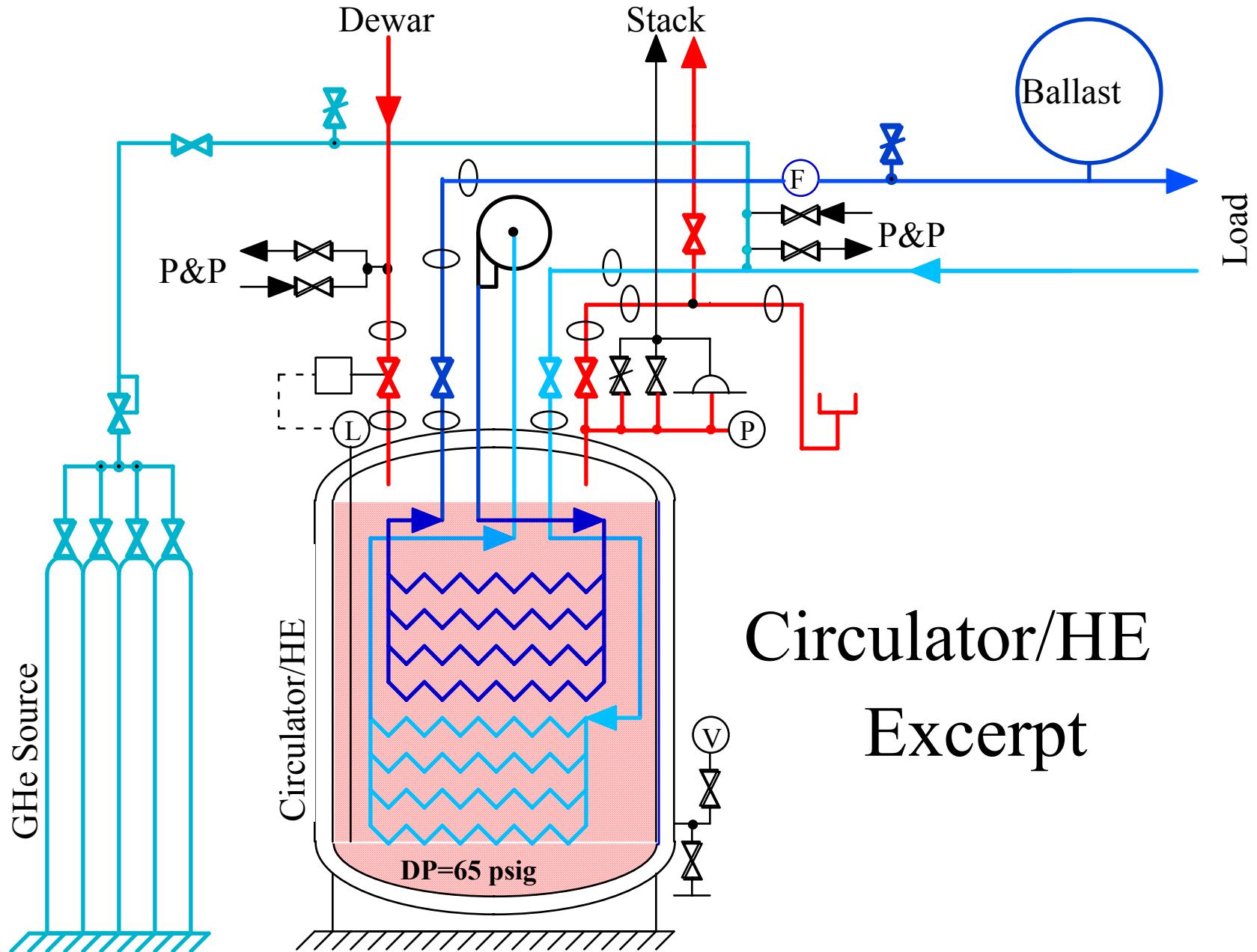
Notes:

- 1). Shown in LH2 cooling mode.
- 2). Mode coupling bayonets are “mutually exclusive”, and serve to “secure” (isolate) the LH2, LN2 systems, see ‘A’, ‘B’ jumper.
- 3). LN2 and LN2 pumped direct and LN2, LN2 pumped and LH2 cooled GHe modes are supported, all cooling modes are supported.
- 4). Pulsed Magnet shown with MIT design vacuum (inner/outer shell) and foam (ends, shell outer) insulation.
- 5). Structural detail of PSM, cryostat not shown.
- 6). “PS Liquid dump” pressurization sparger provisions are TBD.
- 7). Blanked bayonet caps have bleed valves, pressure gauges, not shown.
- 8). VJ lines are indicated as
- 9). The power leads and LN2 intercept piping are not shown.
- 10). GHe VJ piping are hard welded field joints.
- 11). The Circulator/HE Lne2 shield is not shown.
- 12). Shown Cirulating GHe cooled with LH2.
- 13). GN2 connection provided for slow cooldown (check parameters).
- 14). Not all the required relief valves are shown.



E951 Major Interconnections and Line, Ambient Heater, Heater, Vacuum Pump Sizes, Etc.



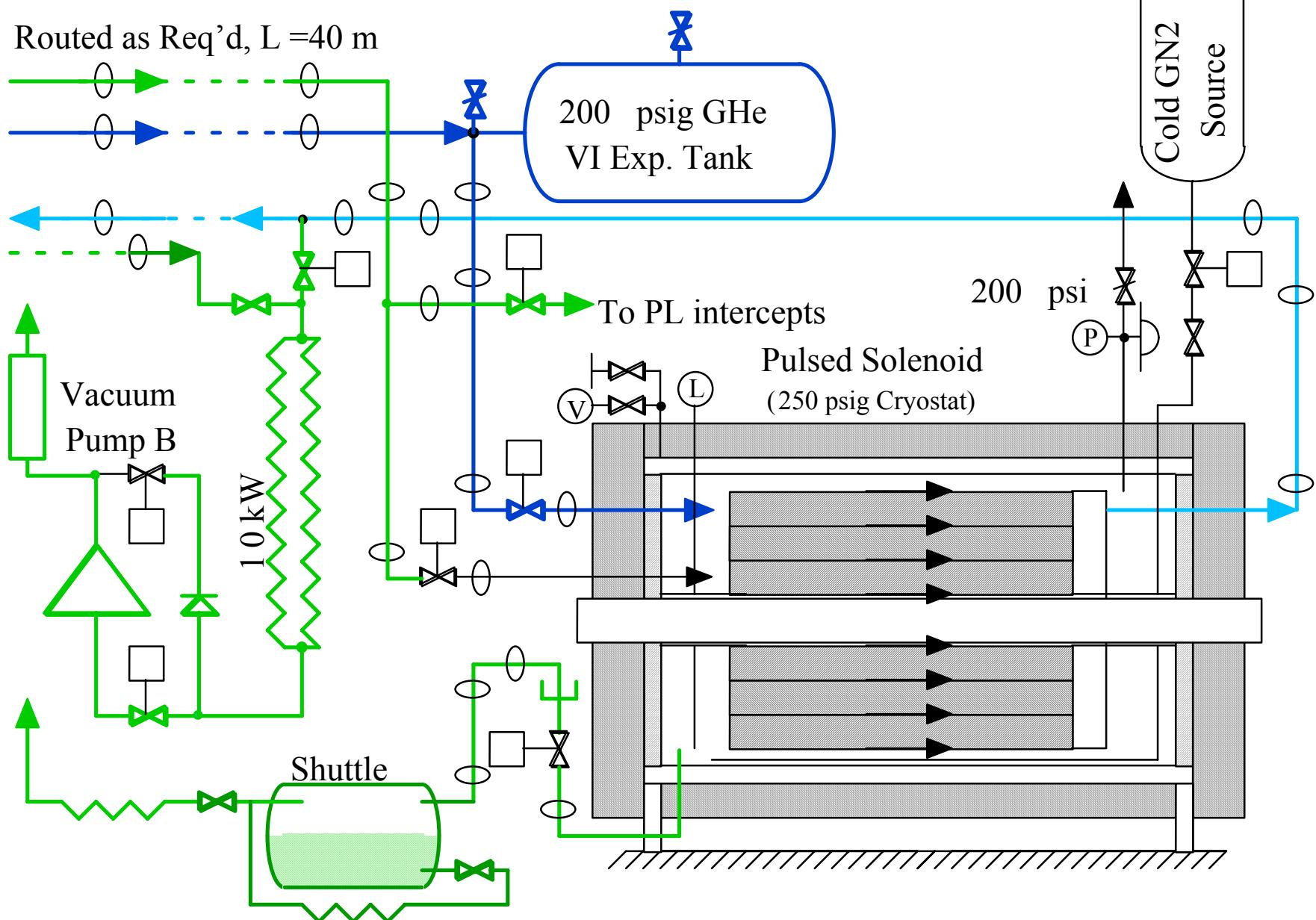


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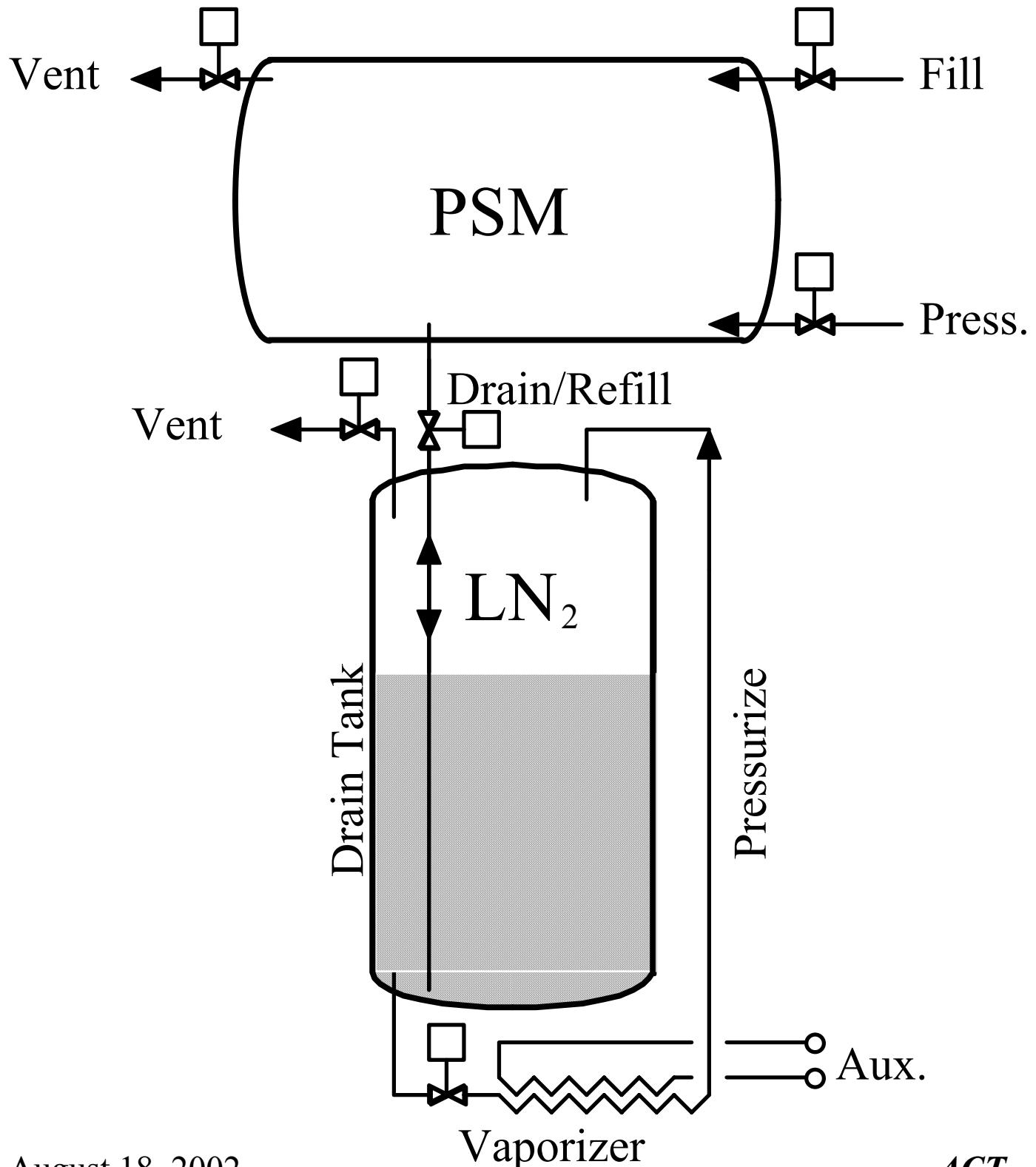
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Pulsed Solenoid Magnet Excerpt



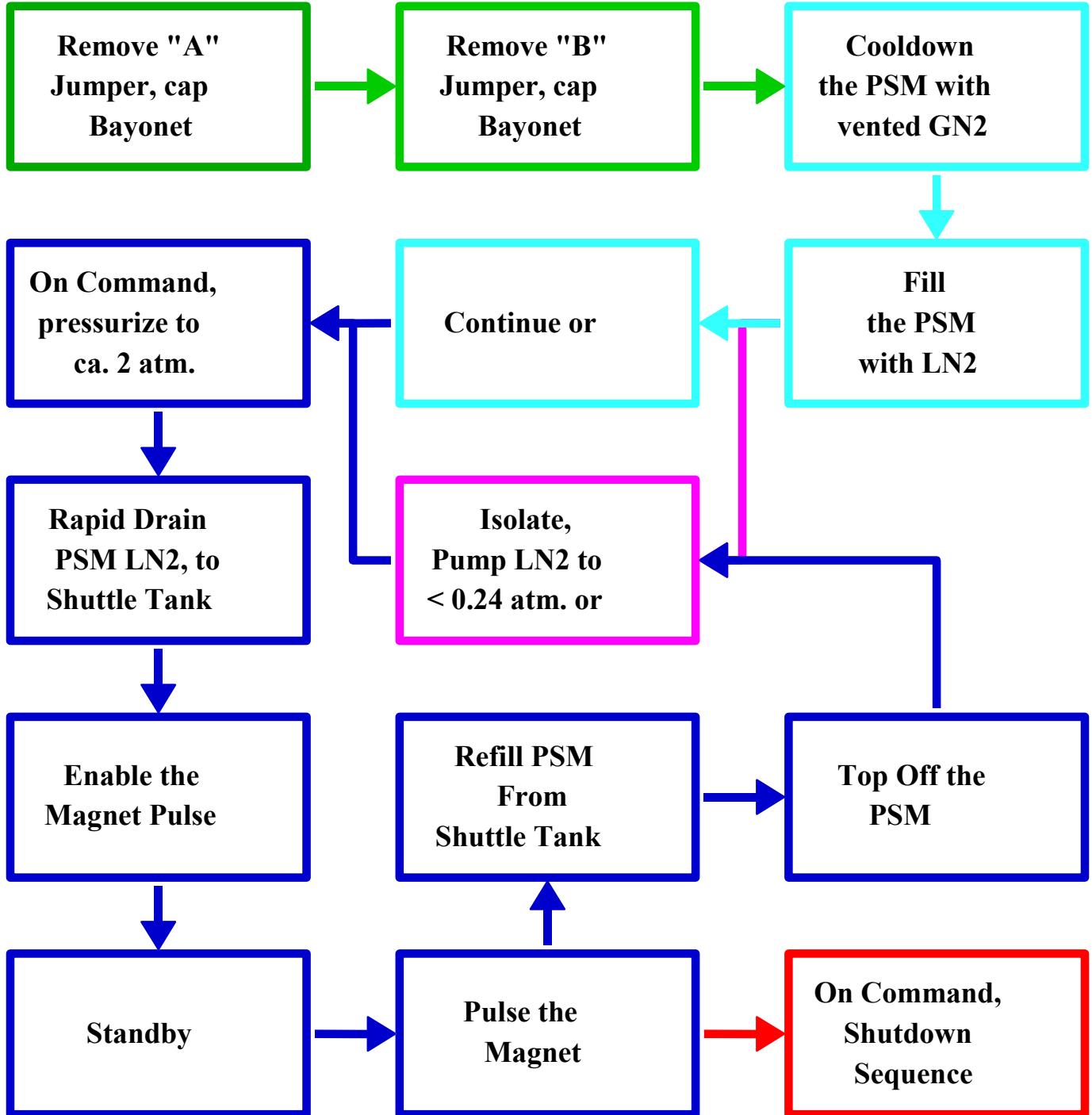
LN_2 Refill Scheme



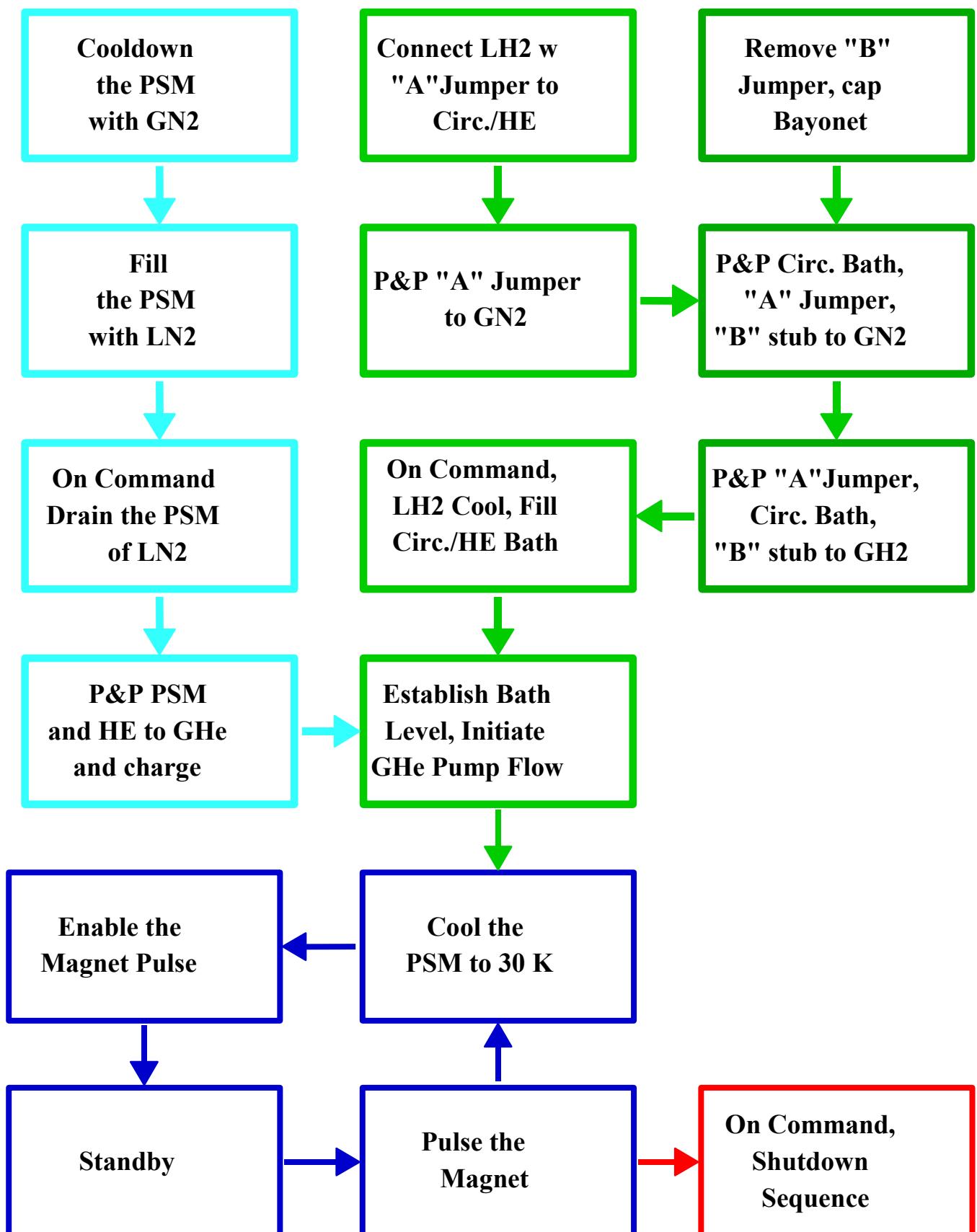
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Liquid Nitrogen, Pumped Liquid Nitrogen



GHe Cooled by LH2









Calculate E951 Relief Flows

E951 LH2 Vessel Vacuum Break and Fire Relief requirements:

LH2, assumed insulation thickness (t) and surface area (A)

Gas of lading.

Ref.: Compressed Gas Association, CGA S-1.3-1995, par. 5.2.2, 5.3.3

Pressure Relief Device Standards - Part 3 -

Stationary Storage Containers for Compressed Gases

Critical pressure of LH2 is 12.98 atmos. This is NOT a critical pressure special case.

Appropriate Eng. form: $G_i = 73.4(1660-T)^*((ZT/M)^{0.5})/CL$

Appropriate Met. form: $G_i = 241(922-T)^*((ZT/M)^{0.5})/CL$

Vacuum Break: $Q_A = F\{T\}(FG_iUA)$

Fire : $QA = FG_iUA^{0.82}$

NOTE: Input variables are marked in **RED**. Derived variables in black.

Vacuum Break Parameter	US Value	US Units	Metric Value	Metric Units	
P _{abs.}	79.67	psia	549.33	kPa	65 psig relief
F	1.00	none	1.00	none	Feed pipe corr.
Constant 1	7.34E+01		2.41E+02		See pg. 26, 27.
Constant 2	1.66E+03		9.22E+02		See pg. 26, 27.
C	356.00		356.00		See table 4.
L	191.50	Btu/lb	445.00	kJ/kg	Heat of Vap.
Z	1.00	none	1.00	none	Compressibility
M	2.00	none	2.00	none	Molecular wt.
G _i	7.49E+00		4.38E+00		notes table 1,2
TC	0.125	Btu/hr ft°F	0.781	kJ/hr m°C	table 3, Hydrogen
t, thickness	0.033	ft	0.010	m	insul. thickness
U	3.80	Btu/hr ft ² °F	77.66	kJ/hr m ² °C	calculate
A, Area	52.62	ft ²	4.89	m ²	Vessel area
T, Temperature	36.70	R	20.39	K	degrees
Constant 3	0.250		0.383		see ¶ 5.2.2
Constant 4	590.00		328.00		see ¶ 5.2.2
Q _A , Vac. Break	127.55	cfm Air	217.27	m ³ /hr AIR	see ¶ 5.2.2
Cross Check	127.88		216.71		Checks OK

Fire Parameter	US Value	US Units	Metric Value	Metric Units	
F	1.00	none	1.00	none	Feed pipe corr.
G _i	7.49		4.38		see above
U	3.80	Btu/hr ft ² °F	77.66	kJ/hr m ² °C	see ¶ 5.3.3
A	52.62	ft ²	4.89	m ²	see ¶ 5.3.3
Q _A , Fire	733.44	cfm Air	1249.55	m ³ /hr AIR	see ¶ 5.3.3

Calculate E951 Relief Flows

E951 LN2 Vessel Vacuum Break and Fire Relief requirements:

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Appropriate Met. form: $G_i = 241(922-T)^*((ZT/M)^{0.5})/CL$

Vacuum Break: $Q_A = F\{T\}(FG_iUA)$

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NOTE: Input variables are marked in **RED**. Derived variables in black.

Vacuum Break Parameter	US Value	US Units	Metric Value	Metric Units	
P _{abs.}	79.67	psia	549.33	kPa	65 psig relief
F	1.00	none	1.00	none	Feed pipe corr.
Constant 1	7.34E+01		2.41E+02		See pg. 26, 27.
Constant 2	1.66E+03		9.22E+02		See pg. 26, 27.
C	356.00		356.00		See table 4.
L	83.48	Btu/lb	194.00	kJ/kg	Heat of Vap.
Z	1.00	none	1.00	none	Compressibility
M	28.00	none	28.00	none	Molecular wt.
G _i	8.38E+00		4.90E+00		notes table 1,2
TC	0.023	Btu/hrft°F	0.145	kJ/hrm°C	table 3, Nitrogen
t, thickness	0.033	ft	0.010	m	insul. thickness
U	0.71	Btu/hrft ² F	14.42	kJ/hrm ² C	calculate
A, Area	52.62	ft ²	4.89	m ²	Vessel area
T, Temperature	139.32	R	77.40	K	degrees
Constant 3	0.250		0.383		see ¶ 5.2.2
Constant 4	590.00		328.00		see ¶ 5.2.2
Q _A , Vac. Break	23.03	cfm Air	39.24	m ³ /hr AIR	see ¶ 5.2.2
Cross Check	23.10		39.14		Checks OK

Fire Parameter	US Value	US Units	Metric Value	Metric Units	
F	1.00	none	1.00	none	Feed pipe corr.
G _i	8.38		4.90		see above
U	0.71	Btu/hrft ² F	14.42	kJ/hrm ² C	see ¶ 5.3.3
A	52.62	ft ²	4.89	m ²	see ¶ 5.3.3
Q _A , Fire	152.34	cfm Air	259.53	m ³ /hr AIR	see ¶ 5.3.3

August 18, 2002

Air Condensation at 20K

A function of air inrush rate, but

W Reference CEBAF Cryounit Loss of Vacuum,
1991 (0.0033kg/s, 749 W/m²)

Take 1 kW/m² for the Circ./HE vessel:

$$\begin{aligned}\text{GH}_2 \text{ boiloff rate} &= (1 \text{ kW/m}^2) * 5\text{m}^2 / (445 \text{ J/g}) = 11.2 \text{ g/s} \\ &= (11.2 \text{ g/s}) / 71 \text{ g/l} = 0.15825 \text{ l/s} \\ &= (0.15825 \text{ l/s}) * 27.8 \text{ scf/l} = 4.399 \text{ scf/s} \\ &= (4.399 \text{ scf/s}) * 60 \text{ s/m} = 263.966 \text{ scfm}\end{aligned}$$

490 kJ/kg is the energy necessary to freeze and cool air to 20 K:

Rate of air solidification:

$$= (1 \text{ kW/m}^2) * 5\text{m}^2 / (490 \text{ kJ/kg}) = 0.0102 \text{ kg/s}$$